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# ENERGY SECURITY: STANDARDS AND GUIDELINES FOR SOLAR PHOTOVOLTAIC INSTALLATIONS INCLUDING TECHNICAL PLAN TO TRANSITION SOLAR PHOTOVOLTAIC PLANT MAINTENANCE TO BE PERFORMED IN-HOUSE FOR AIRPORTS IN SOUTH AFRICA

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***ABSTRACT***

***Establishing renewable energy technologies as a viable long-term strategy for developing countries calls for the documentation of learnings from previous installations and the establishment of an in-house maintenance team for conducting regular maintenance and operations. Documentation of learnings from past installations is necessary to ensure profitable transactions in relation to the logistics of the plant equipment and spares, labour for installation, and design of plant and associated systems. The documentation of learnings should extend to the operations of the plant to mitigate certain undesirable effects at design stage that could not otherwise be foreseen. These undesirable effects include site conditions, testing, operational disruptions, and security. Gradual but certain establishment of an in-house maintenance team is key to better plant performance, plant longevity and ensuring the validity of original equipment manufacturer's guarantees and warranties. This paper presents the standards and guidelines relating to technical aspects of the solar photovoltaic installations at airports in South Africa and the proposed and supported plan for transitioning the maintenance of all plants to be performed in-house.***

***KEYWORDS: Solar PV Plants, Solar PV Modules, Solar PV Maintenance for Airports, Solar PV Installations at Airports, Solar PV Plant Design for Airports & Cost of Maintenance for Solar PV Plants at Airports in South Africa***

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Original Article

## 1. INTRODUCTION

According to the South African Photovoltaic Industry Association, "The sun provides almost all the energy we use for our daily life. Also, all fossil energy like coal and oil are based on energy that came from the sun – albeit billions of years ago. Even wind energy is driven by the power of the sun. Only nuclear power and geothermal power are driven by nuclear reactions. The solar energy reaching the Earth's surface would, in theory, be sufficient to solve all the energy problems on Earth. Outside the Earth's atmosphere solar energy has an almost constant value of 1367 W/m². While passing through the atmosphere, the energy and the spectral behaviour of the sunlight changes. Due to reflections on particles in the air, clouds, as well as ground reflection, the direct irradiation is reduced and a diffuse irradiation is added. The sum of both irradiation types is usually below the value found outside the atmosphere. For a sunny day and optimised orientation towards the sun, the global irradiation is about 1000 W/m². On cloudy days there is almost no direct irradiation left, the diffuse irradiation depends on the cloud type, and can be less than 100 W/m²." [1]

Although solar PV power generation plants currently represent a small percentage of global power generation, installations are growing rapidly for both utility-scale and distributed power generation applications.

Reductions in costs driven by technological advances, economies of scale in manufacturing, and innovations in financing have brought solar power within reach of grid parity in an increasing number of markets. Continued advancements and further cost reductions will expand these opportunities, including in developing countries where favourable solar conditions exist, as in South Africa. Policy environments for renewable energy in the developing world are being refined, drawing on the lessons learned from the successes and failures of policies adopted in first-mover markets. Several regulatory models are being successfully deployed in the developing world with consequent increase in investment and installations. This rapid market growth has been accompanied by an observed uneven expertise and know-how demonstrated by new market entrants. Building capacity and knowledge on the practical aspects of solar power project development, particularly for smaller developers, will help ensure that new PV projects are well-designed, well-executed, and built to last [2].

The curve of standardisation for technological innovation can be seen in Fig. 1. With time, the development of technologies calls for the need for certain levels of quality, such as standards guaranteeing safety, functionality and compliance with various legislative requirements concerning materials and environmental sustainability. Standardisation is useful in the reduction of variety and also makes for cost effective mass manufacturing and after-market services such as maintenance, upgrading, refurbishments, etc. Standardising in solar PV plant installations allows for cost effective installations, making use of economies of scale for solar PV panels, electrical and control systems and software platforms as well as familiarity in operations and maintenance.

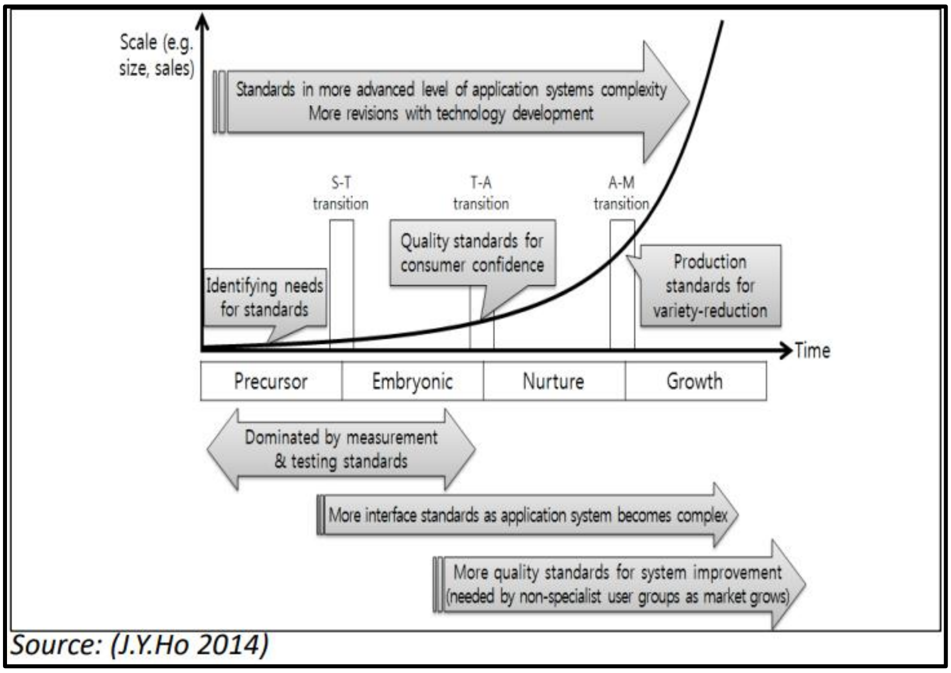


**Figure 1: Standardisation in Technological Innovation [3].**

Table 1 shows the various organisations that are involved in solar PV standards development. There are six major organisations identified in this study as seen in Table 1.

**Table 1: Organisations involved in solar photovoltaic standards development**

| | Standards Development Organisation | | Membership | Focus of Activities |
|---|---|---|---|---|
| 1 | International Electrotechnical Commission | IEC | National committees | Performance and safety of products, systems and services |
| 2 | ASTM International (formerly American Society for Testing and Materials) | ASTM | Individual experts | Measurement principles and specialty tests |
| 3 | Semiconductor Equipment Manufacturers' Institute | SEMI | Member companies | Primarily manufacturing related (materials and equipment) |
| 4 | Underwriter Laboratories | UL | Invited experts | Product safety |
| 5 | International Code Council | ICC | Invited experts | Building and fire codes |
| 6 | Institute of Electrical and Electronics Engineers | IEEE | Individual experts | Grid connection codes |

The first solar photovoltaic (PV) plant to be established at an airport in South Africa was at the George Airport in the Eastern Cape province. It was under construction mid-2015 and was operational in 2016. Soon after this installation was commissioned, two other solar PV plants were installed and became operational in the second half of 2016. Airports Company South Africa (ACSA), South Africa's airport authority, planned three more solar PV plants that were in the design and build stage, passing the prefeasibility stage at the time (financial year 2017/18). It was then decided that the designs of the upcoming plants must capture learnings established from the previous three installations and include them in their designs and installations. The technical learnings from the solar PV plants installed at George Airport, Kimberley Airport and Upington International Airport (UPIA) were captured and are contained in this paper and were included in the design and construction specifications of the solar PV installations at Port Elizabeth International Airport (PEIA), Bram Fischer International Airport (BFIA) and East London Airport.

Outsourcing the maintenance of these plants can become costly with many routine tasks being done by different service providers at different geographical locations, secured at different rates. With this arrangement, similar problems are sometimes re-investigated multiple times with maintenance taking place in isolated forms. With a large investment in solar PV already across the airport group and future aspirations of adopting solar PV for offsetting carbon footprint of airports, it is in the best interests of the company to transition maintenance so that it is performed in-house. ACSA has five solar PV plants at the following airports and a sixth planned for East London Airport (650 kWp).

- George Airport (750 kWp)
- Upington International Airport (500 kWp)
- Kimberley Airport (500 kWp)
- Port Elizabeth Airport (1000 kWp)
- Bram Fischer International Airport (750 kWp)

This paper presents the standards and guidelines that were implemented at PEIA, BFIA and are planned East London Airport based on the installations done at George Airport, UPIA and Kimberley Airport. This paper also presents the plan to transition the maintenance and operations of the plants in-house.

## 2. STANDARDS AND GUIDELINES FOR SOLAR PV INSTALLATIONS AT AIRPORTS

Figure. 2 shows the approach used to draft the standards and guidelines for solar PV installations. The clauses included in the standards and guidelines for solar PV installation were workshopped with the technical staff and technical management at the airports prior to their adoption at airports.

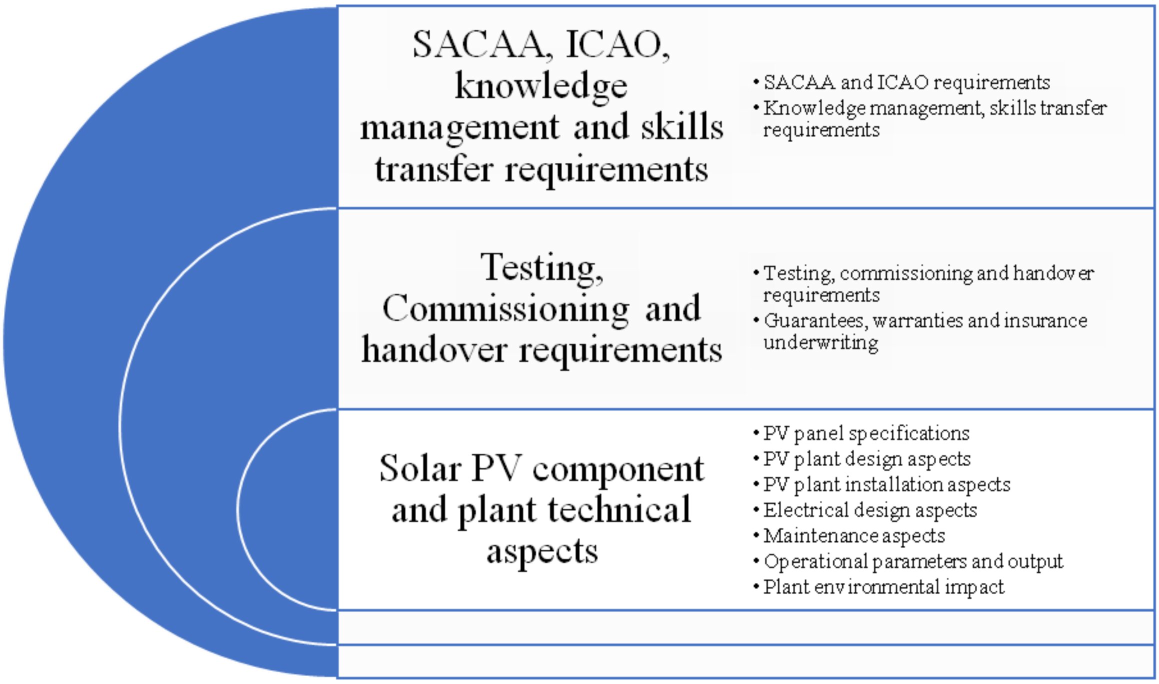


**Figure 2: Approach to Drafting Standards and Guidelines for Solar PV Installations**.

The clauses address the solar technical aspects of the plant, the project aspects of testing, commissioning and handover, as well as business imperatives and operating environment requirements, such as legislative requirements of the business and operating environment, and the skills transfer requirements.

### 2.1 Solar PV Plant Design Aspects

- Performance ratio of the solar PV plant must be optimised to a minimum of 0.8.
- The control and integration software in the PV plant shall be open source.
- The design of the PV plant must consider future expansion.
- The design of the PV plant shall be of a modular type allowing easy maintenance and repair.
- The design of the PV plant shall allow for additions of power storage and integration of back-up power supply.
- The design of the PV plant shall make provision for the installation of monitoring equipment for importing/exporting of power in compliance with National Regulatory Standards, NRS 048/9.
- The solar PV design stringing shall consider down-time and risks with respect to the loads being fed.
- Design must allow for ease of maintenance such as washing of PV panels; rainwater harvesting should be considered at design stage for the purposes of washing of panels.

- Design must consider maintenance of the performance ratio during times of corrective maintenance.
- A prioritising controller shall be included and integrated to ensure that the solar PV plant can generate electricity for the site in the absence of electricity from the national electricity grid.
- A monitoring system to improve the reliability and productivity of the plant shall be installed in accordance with IEC 61724 Ed 1.0 Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis. The monitoring system shall include the monitoring of plant performance to optimise the energy output, detect abnormal losses and be use for planning preventative maintenance actions.
- The installation shall ensure that solar PV yield is being used first before electricity from the national electricity grid is used for the site.

**2.2 Solar PV Panel Specifications**

- The semiconductor material to be selected for PV plants shall have a minimum cell efficiency of 20.3 % with a minimum lifespan of 25 years.
- Solar PV panels that do not incorporate integrated bypass diodes that cause adverse effects when it comes to shading (particularly thin film technology) shall not be used.
- Factory acceptance electroluminescence tests must be submitted with all panels purchased. Variations of +-5W are allowed in PV panel output wattage and must be clearly stated.
- The PV panels chosen shall be compliant and certified to the following IEC standards: [4]
  - IEC 61215-2:2016 Terrestrial photovoltaic modules – Design qualification and type approval
  - IEC 60068 -1: 2017 Environmental testing
  - IEC 61730-1:2016 Photovoltaic module safety qualification – Requirements for construction
  - IEC 61730 -2:2016 Requirements for testing
  - IEC 61701-2:2011 Salt mist corrosion testing of photovoltaic modules
  - IEC 60891:2009 Procedures for temperature and irradiance corrections to measured I-V characteristics
  - IEC 60904-1:2006 Measurement of photovoltaic current-voltage characteristics
  - IEC 60904-3:2016 Measurement and principles
  - IEC 60904-5:2011 Determination of equivalent cell temperature (ECT)
  - IEC 60904-8: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices (where applicable)
  - IEC 61853: Performance testing and energy rating.
- The equipment should be able to operate at nominal operating cell temperature or NOCT of 45 ℃ $\pm$ 3 ℃ and operating temperature of between -10 ℃ and 80 ℃ at maximum operating system voltage of 1000 V DC [4].

- The following information should be made available in writing from the solar PV module manufacturer: [4]
    - Confirmation of surface texturing applied to the panel to reduce reflection and surface reflection parameters of the panel
    - Confirmation of the application of silicon nitride or other treatments to optimise optical properties
    - Confirmation of edge isolation done and the series and shunt resistances
    - Confirmation of the treatment of lightly diffused phosphorous emitters to reduce recombination losses and avoid the existence of a dead layer at the cell surface
    - Confirmation that design minimises metal contact areas to reduce resistance and heavy doping beneath the contact areas to reduce recombination
    - Confirmation of rear and front surface passivation
    - Confirm recyclability of the panel.
- A glare study confirming no glare to aircraft pilots from the solar PV installation shall be completed.
- The junction boxes must be at least IP67 rated.

**2.3 Solar PV Plant Installation Aspects**

- Transportation and handling shall be as per manufacturer's recommendation and in absence of this, the panels shall be transported in a vertical arrangement. Freight forwarding documentation shall be included in the handover documentation and shall be checked prior to installation of the solar PV plant.
- The installation of PV panels shall consider the ground or installation surface conditions, shading, and direction of solar irradiation, for optimum capture of solar energy.
- All ground installations shall be preceded by an environmental impact study.
- Soil resistivity tests should be undertaken for ground mounted installations.
- Fixed or tracking arrays shall be decided based on feasibility.
- A lightning risk assessment shall be done.
- Evaluation including execution of a study of shadows falling from aircraft landing and taking off and from fixed structures to ensure that performance ratio of plant is not affected.
- Mounting structure must comply with the following standards:
    - SANS 10160 Part 2 – Self weight and imposed loads
    - SANS 10160 Part 3 – Wind actions.

**2.4 Electrical Design Aspects**

- The following must be complied with for the PV plant installation:
    - IEC 60364-4-41: 2017 Protection for safety, protection against electric shock

  - IEC 60364-4-43:2008 Protection against overcurrent
  - IEC 60364-4-44:2007 Voltage disturbances
  - The minimum insulation resistance shall be 20 MΩ when measured at 500 V DC
  - IEC 60364-7-712:2017 Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems
  - IEC 61730-2:2016 Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
  - IEC 61439-1:2011 Low-voltage switchgear and control-gear assemblies
  - IEC 60529 Ingress protection code
  - IEC 60099-6:2002 Protection against transients and overvoltage
- All solar PV systems shall utilise 400 V to 11 KV step up transformers, star-delta vector configuration.
- For security of supply all installations shall be grid tied with priority given to the solar PV plant supply.
- The inverter system voltage shall be designed for 1000 V DC and input voltage shall be 400 V to 800 V and output voltage 400 V.
- The inverters shall be of string inverter type.
- The operating voltage ($V_m$ x number of modules in series at all temperatures at the installation location) shall fall within the inverters maximum power point tracker (MPPT) voltage range.
- The total $I_{sc}$ current for strings in parallel shall be lower than the maximum input current for the inverter.
- Panel stringing must consider the panel output wattage from factory acceptance electroluminescence (EL) tests.
- Inverter shall include a protection for anti-islanding (in accordance with NRS 097-2-1 "Inverter type test certificate and test report").
- Inverters must include the following protection functions:
  - DC reverse polarity protection
  - Reverse current protection
  - ESS switch disconnector
  - AC short circuit protection
  - Ground fault monitoring
  - Galvanically isolated
  - All-pole sensitive fault
  - Current monitoring unit
  - DC overvoltage protector type II

  - String failure detection
  - Protection class 1
  - Overvoltage category III.
- All inverters must carry an ingress protection rating of 66 (IP66).
- All inverters shall be programmed such that solar PV energy is used first before grid power is used.
- The PV plant may be designed to accommodate battery storage.
- Orientation of the module strings and array strings will be based on the anticipation of shading to ensure optimum output.
- The cabling shall be such that it avoids enveloping the panel with transient currents.
- Remotely controlled breakers should be employed at substations.
- A meter that is AMR (automatic meter reading) compatible shall be installed to accurately determine output of plant being used for the site.
- Verification and documentation of fault current must be done.
- Verify electrical ring network protection settings, the final protection settings are to be included in handover documentation, out of sync settings must be corrected.
- The inverter shall comply with the following standards:
  - IEC 60364-7-712 (requirements for DC switch)
  - IEC 62109 Safety requirements
  - IEC 62116 performance of islanding prevention.
- Inverters must be protected from weather conditions.
- The combined cable losses should not exceed 3 %, i.e. the AC and DC cable losses combined.
- Cables used in outdoor environment shall be UV (ultraviolet) resistant.
- Cables should have a class II rating for insulation.
- Cables must be rated for temperatures from -40 ℃ to +90 ℃.
- Cables shall comply with SANS 1507.
- Cables must be installed in conduits and hooded cable trays. The cable return path should ensure that induction loops are avoided.
- Cables shall be terminated with MC4 connectors.
- All connectors shall be UV resistant, ozone protected, being temperature rated equal to or better than -40 ℃ to +90 ℃, having an IP class of at least 65. They must be equipped with a locking system to avoid disconnection of

the parts. Male and female connectors will be of the same make.

- The lightning protection must be designed in compliance with SAN 10313 and IEC 62305.
- Earthing shall comply with 10142 Parts 1 (LV) and 2 (MV), SANS 10292 and SANS 10199.
- Surge protection devices must be installed at string box, combiner box, inverter (AC and DC side) and at transformer level.

**2.5 Solar PV Maintenance Aspects**

- Only competent personnel trained in the maintenance and operation of the photovoltaic system shall be allowed to perform maintenance on the plant. This includes working near or on live equipment and in a live chamber. At least two people shall work on maintenance at any point in time. All isolation procedures shall be in accordance with the high-voltage regulations, i.e. ORHVS **-** operating regulations of high voltage system.
- No cleaning shall occur before sunset and after sunrise.
- For all installations, critical spares (up to 10 %) shall be procured and stored on site.
- Connectivity shall be in accordance with ORLVS – operating regulations of low voltage systems.
- All maintenance shall be in accordance with original equipment manufacturer (OEM) recommendations.
- Where feasible, alternative water sources should be implemented for the washing of the PV panels.
- The project shall purchase a portable I-V tracer, infrared camera and signal transmission device for verification of availability and reliability of the PV plant.
- Maintenance shall be done to maintain the warranty and guarantee of all plant equipment and the performance ratio to above 0.8.
- All spares and replaced components shall be of equal quality or exceed the original quality subject to its compatibility with the solar PV plant.
- Full report shall be done in the event of the failure of a PV panel or other system component before the guarantee and or warranty period, to establish the root cause and put in place preventative maintenance measures.
- Should the performance ratio of the plant fall below 0.8, a full investigation and report shall be produced to the plant owner by the installation contractor during the defects liability period and the maintenance contractor during the respective maintenance period and any warranty or guarantee claim shall be handled respectively by these contractors.
- The contractor shall carry out all operations and maintenance in the defects liability period to achieve the energy production and the following services are a minimum:
    - Regular operation
    - Scheduled maintenance
    - Preventative maintenance as per manufacturer manuals and best practice

  - Daily plant performance and functional monitoring
  - Administrative and financial services
  - Management of alarms and events
  - Predictive maintenance as per manufacturer manuals and best practice
  - Corrective maintenance
  - Quarterly performance and operations and maintenance (O&M) reporting, including keeping an O&M logbook
  - Spare parts management
  - Management of the insurance policies.
- Calibration of all equipment must be done upon handover of plant from the maintenance period, defects liability period, intermediate acceptance period or whenever, there is a handover from one party to another for whatever reason.

**2.6 Solar PV Operational Parameters and Plant Output**

- For electrical energy contributed to the grid, a memorandum of understanding shall be drawn up with the respective municipalities based on the local utility bylaws.
- The quality of electrical supply from the PV plant shall comply with the NRS 048 part 2 and part 4.
- Power quality monitoring equipment shall be installed on the PV plant before connection to the grid.
- Power quality incident logging shall be stored and backed up on the server. Critical alarms shall be relayed immediately to the plant's responsible person. Other alarms shall be relayed to the infrastructure monitoring and control (IMC) team.
- Monitoring of PV module and PV plant performance shall be in line with IEC 61724-2:2016.
- The expected linear or stepped power output warranty period of the solar modules shall be at least over 25 years.
- Any performance ratio deviation outside 0.8 shall be investigated in the context of the warranty.
- Any deviation in the performance of the plant from the linear performance warranty shall be investigated by the manufacturer.
- Should the PV plant be generating electricity into the national electricity grid, this must be granted approval from the relevant regulatory bodies, such as the National Energy Regulator of South Africa (NERSA) prior to plant installation.
- The plant shall have separate metering for import and export and must be compliant with SANS 474/NRS057.
- A weather monitoring station shall be installed on the plant that allows for plant performance ratio calculations according to IEC 61724 Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis.

- A monitoring system must be installed to monitor data that must be used for optimising energy output, detecting abnormal losses and planning preventative maintenance actions.
- The monitoring system must be able to record meteorological data, electrical parameters and status of the PV plant components.
- Continuous monitoring is required.
- The minimum data to be monitored are as follows:
  - DC current and voltage at combiner box level
  - Inverter behaviour
  - DC current and voltage input
  - Output active and reactive power
  - Phase voltage and current
  - Energy output
  - Alarms and faults
  - Meteorological data – Module temperature on 1 % of the plants' modules, ambient temperature, irradiation, wind speed
  - Energy output at the meters (import and export, plant yield)
  - Status of the equipment (protection devices, inverters)
  - Any other information which will be required by the laws and norms in respect of this installation.

**2.7 Guarantees, Warranties and Insurance Underwriting**

- Performance warranty of the solar PV panels shall be a minimum of 25 years and a total of 20 % linear degradation as a maximum over 25 years. Solar panel warranty of 25 years must be insurance backed, with full details of claim procedure and insurance backing submitted. Plant registration with the supplier is the responsibility of the installation party appointed.
- Upon installation, registration documentation of the photovoltaic plant installed must be submitted.
- Verification certificate that certifies that commissioning was conducted per the standards and requirements of the warranty.
- The monitoring system must be designed and implemented in such a way to have a lifetime of 25 years.
- The mounting structure shall have at least 10 years warranty and shall be designed for a minimum lifetime of 25 years. Corrosion prevention must start at the design stage considering site and soil specific parameters.
- Inverters must have at least a 5-year warranty, with a clearly defined claiming procedure.
- The conditions which void warranties for all equipment and installations must be clearly stated, preserved and

communicated to the plant owner and all handling parties.

**2.8 Environmental Impact**

- Disposal method of the plant and its equipment at end of lifespan shall be decided based on the outcomes of a feasibility study, environmental impact study and the objectives of the business.
- The installation contractor shall be liable for any environmental impacts arising from the plant installation during the defects liability period.
- The maintenance contractor shall be liable for any environmental impacts arising from the plant maintenance activities during the maintenance period.

**2.9 Testing, Commissioning and Handover**

- Commissioning shall be done per the following standards:
  - IEC 62446: Grid connected photovoltaic system
  - IEC 60364-6: IEC 60364-6: Low voltage electrical installations – Part 6: Verification
  - IEC 62337: Commissioning of electrical, instrumentation and control systems in the process industry – Specific phases and milestones.
- The following shall be submitted upon handover:
  - Approved as-built drawings and design report signed by a professional engineer, registered with the Engineering Council of South Africa (ECSA)
  - Operating and maintenance documentation
  - Equipment datasheets
  - Calibration certificates of all equipment
  - Verification certificate that certifies commissioning was conducted per the standard IEC 62446 Grid connected photovoltaic systems
  - I-V curves
  - PV panel electroluminescence (EL) tests
  - Signal transmission device data
  - Testing and commissioning data including but not limited to details of PV array, results of polarity, insulation, grounding, voltage and current tests
  - Test certificates that certify compliance with relevant codes and standards listed for the photovoltaic plant components and systems
  - Factory acceptance tests (FAT)
  - Open circuit voltage

  - Short circuit current
  - Continuity of grounding system
  - Integrity of electrical insulation on power circuits
  - Operating voltage
  - Operating current
  - Verification of fault current and electrical ring network protection settings
  - Whole system performance (performance ratio which is actual output to predicted output).

- Competent representatives from both the client and the contractor shall be present for FAT.
- Performance ratio must be calculated according to the standard CEI EN 61724 (CEI 82-15) standard. Inverter availability must be established and exceed 0.85 as calculated below. The following equations will be used to calculate the inverter availability and the plant annual availability:

$$Inverter\ Availaility(\%) = \frac{\sum OT + \sum TnAC}{TOT} \times 100$$

Where:

TOT Total theoretical operating time [minutes]. (This accounts for the total amount of time in which an inverter (i) exceeds the minimum irradiation threshold of 30 W/m².)

OT Operating time [minutes]

TnAC Time of non-availability [minutes] with causes not attributable to the contractor. During these periods, all inverters are considered as available. In this case, the operator must provide satisfactory evidence.

The operating time is calculated as the time when each inverter was considered as available. The requirement is that there is voltage in the output terminals of the connection box and the ratio of the actual production (Pi,ind) divided by the average production (PAV) of all inverters exceeds 0.85. This requirement is applied with the granularity of 15 minute periods. For such period of computation:

if Pi,ind/PAV > 0.85, the inverter i is considered as available,

if Pi,ind/PAV < 0.85, the inverter i is considered as not available,

Where:

Pi, ind actual production of the inverter i in fifteen minute periods

PAV average production of all inverters in fifteen minute periods.

- The following tests must be performed as a minimum (not limited to):
  - Mechanical completion test to ensure that all parts of the facility has been physically checked completed and installed correctly and according to the as-built documents. Once the mechanical completion of the installation is achieved, the contractor will proceed to energise the facility and carry out the tests for

completion to ensure each component of the plant is working properly and in accordance with the national and local electricity grid codes. It is the responsibility of the contractor to deliver a grid code compliant plant.

  - Provisional acceptance tests (Phase 1 of IEC 62446) shall be performed to confirm the performance ratio of the entire facility and quality of design, construction and correct operation and must be supervised by an independent technical adviser.
  - Intermediate acceptance tests (Phase 2 of IEC 62446) shall be performed where the performance and availability verification are executed for a period of 1 year. A visual inspection and thermal analysis (using thermal camera) is made on the plant to check for possible defects.
  - Final acceptance tests (Phase 3 of IEC 62446) shall be performed for two years after the provisional acceptance tests. All remarks made during the provisional acceptance tests are verified as complete and a final performance and availability verification in this two-year period.

- Minimum requirements for taking over are as follows:
  - All works as per the contract are complete
  - Tests on completion have been passed and approved by the plant owner
  - Final O&M manuals for the works have been issued to the plant owner
  - List of open points has been agreed and signed by the plant owner and contractor
  - Provisional and final acceptance tests have been successful in meeting the minimum guaranteed performance and availability over the periods of analysis.

**2.10 South African Civil Aviation Authority (SACAA) and International Civil Aviation Organisation (ICAO) requirements**

- Any PV installation within the aerodrome vicinity shall be of an anti-glare nature and simulation with the "Solar Glare Hazard Analysis Tool" must be done in partnership and agreement with SACAA requirements.
- In cases where the height exceeds the maximum height in a roof mounted installation, obstruction lights shall be installed according to civil aviation regulations, CAR 139.01.30.
- Prior approval and consultation with all relevant stakeholders shall be acquired for solar PV installations within the airport environment.
- The solar PV installation shall not infringe any airports operations, safety, security or operational licence requirements as dictated by ICAO and SACAA regulations.

**2.11 Knowledge Management, Skills Transfer and Learnings**

- The consultant shall ensure that the site agent maintains a daily log of all events, occurrences and progress for the duration of the installation until commissioning of the solar PV installation.

- The consultant shall ensure that the project manager and design engineer compile a list of learnings from the design and installation of the facility which is to be attached to the close out report to be included in the handover documentation.
- The maintenance contractor shall compile a list of learnings from the maintenance of the solar PV plant which can be viewed from time to time and must be submitted annually to the ACSA person managing the maintenance contract.
- The installation contractor shall submit to the plant owner a comprehensive report on the supply market for solar PV panels, solar cells, inverters, transformers, software and sensors, mounting structures, and all other equipment and tools utilised for the installation.
- The consultant shall ensure that knowledge on all aspects of the plant design, supply process, installation and commissioning and project management is transferred to at least two of the plant owner's personnel.
- The maintenance site manager shall ensure that knowledge transfer is done through regular technical updates and, if need be, practical demonstration sessions as chosen by the plant owner's managing personnel.
- During the twelve-month defects liability period, performance ratio must be maintained at above 0.8 and all activities and steps taken to ensure this performance ratio must be documented and submitted as a report to the plant owner.
- The maintenance contractor shall be key in facilitating any research done by a research student from a university or other tertiary institution.
- The following shall be communicated as a minimum as per the learning and skills transfer:
  - Basic concepts on solar PV panel technology
  - Theoretical introduction to commissioning and test programmes
  - Practical introduction to correct use of maintenance manuals
  - Basic trouble shooting and fault finding
  - Safety procedures for operating and maintaining the plant
  - Theory and practice of electrical power system. Operational activity that is permissible by the plant owner for their personnel during the warranty period
  - Safety methods for equipment isolation during maintenance
  - Description of the electrical system including details of LV and data cable routes
  - Identification of protection relays and equipment
  - Review of protection relay settings
  - Description interface with any existing substation equipment and with the utility grid
  - Replacement of minor parts (e.g. fuses)

- Safety access, operations and maintenance procedures where special procedures are required which would not be familiar to experienced, qualified/registered personnel
- Monitoring and interpret a performance report.

## 3. PLANS TO ESTABLISH MAINTENANCE AND OPERATIONS OF SOLAR PV INSTALLATIONS AT AIRPORTS IN SOUTH AFRICA

The plan presents a solar PV maintenance schedule for the next 3-year period of the solar PV maintenance term including the cost saving analysis performed that has a mix of insourced and outsourced tasks, including knowledge requirements for full insourcing to be adopted based on:

- Operational cost savings to the business
- Benefit of standardisation of maintenance across airports for solar PV installations
- Utilisation of in-house skills for tasks that can be executed by internal personnel
- Maximisation of existing maintenance contracts such as electrical reticulation
- Cultivating in-house skills for the full insourcing of solar PV maintenance over a 3-year period, potential commercialisation opportunities

ACSA's five solar PV plants produce yield whose value is around ZAR 6.4m per annum. These solar PV plants require maintenance to ensure their optimal output, execution of preventative maintenance and maintaining the plant's equipment guarantees and warranties. Maintenance can cost around ZAR 980k per plant. Refer to Table 2. It will cost between ZAR5m and ZAR6m to renew 3-year maintenance contracts for all six solar PV plants within the group.

The range of skills required to perform the work as can be seen in Table 2 are varied between labourers, semi-skilled and skilled workers mainly within the electricians and electrical engineering fields. All these skills are entirely possible to cultivate in-house. Due to the financial impact of the COVID-19 pandemic on the business, coupled with the business imperatives to build technical capacity in-house, a solar PV maintenance schedule that takes a hybrid approach as follows is proposed:

- Do certain maintenance tasks in-house
- Include medium voltage (MV) maintenance under the airports' general MV maintenance contracts
- Outsource the remaining tasks under the usual 3-year solar PV maintenance contracts

An analysis was conducted of the potential cost savings with this approach and it was found that 30 % (ZAR 1.7m) cost savings could be realised over the next three years (Table 3).

**Table 2: Estimated Cost of Solar PV Maintenance**

| Solar PV Maintenance Cost (2017) | | | Solar PV Maintenance Cost (2020) | |
|---|---|---|---|---|
| | **ZAR per Annum** | **CPI Escalation** | **Estimated cost per Annum (ZAR)** | **CPI escalation** |
| Year 1 maintenance charge | 258 297.34 | | 307 636.26 | |
| Year 2 maintenance charge | 273 795.18 | 6.00 % | 326 094.44 | 6.00 % |
| Year 3 maintenance charge | 290 222.89 | 6.00 % | 345 660.11 | 6.00 % |
| Total | 822 315.41 | 12.00 % | 979 390.81 | 12.00 % |
| **Cost of Labour** | | | | |
| | **ZAR per Hour 2017** | **ZAR per Hour 2020** | | |
| Labourer | 62 | 73.16 | | |
| Semi-skilled | 134 | 158.12 | | |
| Skilled | 226 | 266.68 | | |
| Site manager | 438 | 516.84 | | |
| Engineer/ Technologist | 1307 | 1 542.26 | | |

**Table 3: Cost Savings for Hybrid Approach (Insource/Outsource) of Solar PV Maintenance**

| Maintenance Task | Frequency | Cost Saving (ZAR) | Notes |
|---|---|---|---|
| Array and Grid Junction box maintenance | Annually, with two follow up checks | 21 334[1] | [1] Skilled labourer rate calculated for 4 days for annual check-up, 3 days each for the two follow ups. Includes analysis of thermographic scans, including 1 day for corrective maintenance (in the 4-day annual check-up). Excludes cost of connectors for corrective maintenance |
| Earthing integrity check, maintenance and corrective action | Annually | 6 400[2] | [2] Skilled labourer rate calculated for 3 x 8 hour days. Includes corrective action. Excludes corrective action material |
| LV and MV cabling integrity checks and corrective action | Annually | 21 334[3] | [3] Skilled labourer rate calculated for 10 x 8 hour days. Excludes corrective maintenance. LV- in-house, MV to be done by a separate service provider |
| Structural integrity check and corrective action | Annually | 6 400[4] | [4] Skilled labourer rate calculated for 3 x 8 hour days. Excludes corrective maintenance |
| Vegetation management | At least twice a year - maintain vegetation height | 37 949[5] | [5] Semi-skilled labourer rate calculated for 3 people, 5 days x 2 times a year for 8 hours per day. Excludes cost of equipment, materials and fuel |
| **Total Savings (Zar)** | Per plant per annum | **93 418 (30%)** | The cost saving represented here assumes that the value of the contract awarded will exclude costings as per itemised costing of a typical contract. It does not take into account the market dynamics at the regional airports or the associated cost of doing business in these regions |
| | Per plant for a three-year contract | **297 070 (30%)** | |

The solar PV plant maintenance schedule (Table 4) with insource/outsource model for cost reduction including knowledge management requirements (Table 5) for full insourcing model proposed for adoption in ACSA was co-developed with UPIA's Maintenance Manager with input from George Airport's Maintenance Manager. Table 6 explores the typical work involved with the insourced solar PV tasks, the skills and certifications required, as well as any special

equipment needed to perform the work involved.

**Table 4: Proposed Model for Transitioning Solar PV Maintenance in-House for Solar PV Installations at Airports**

| | Task | Minimum Frequency | Specific Requirements | In-House/ Outsource |
|---|---|---|---|---|
| Solar PV Plant Major Components | **Array and grid junction box maintenance** | Annually, with two follow up checks | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | In-house |
| | **Inverter maintenance** | Annually | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | Outsourced |
| | **Substation and transformer maintenance** | Annually | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | To be done by the airports' existing medium voltage (MV) service provider |
| | **Photovoltaic panels maintenance** | Cleaning at least twice a year, with spot cleaning (for bird droppings and others) every two months | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | Outsourced |
| | ***Maintenance of battery storage system** | At least twice a year, following OEM recommendations | Not applicable | |
| Solar PV Plant Supporting Systems | **Solar PV module connection integrity and corrective action** | Twice a year | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | Outsourced |
| | **Earthing integrity check, maintenance and corrective action** | Annually | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | In-house |
| | **LV and MV cabling integrity checks and corrective action** | Annually | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | Low voltage (LV) in-house. MV to be done by a separate service provider |
| | **Structural integrity check and corrective action** | Annually | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | In-house |
| | **Solar PV panels thermographic imaging and corrective action** | Twice a year | | Outsourced |
| | **Vegetation management** | At least twice a year and as required to maintain vegetation height | Maintenance of vegetation height at 10 cm | In-house |
| Solar PV Balance of System | **Maintenance and calibration of meteorological equipment** | Annually | Maintained according to OEM requirements, ensuring optimal performance and preservation of warranties and guarantees | Outsourced |
| | **Auxiliary and ancillary systems maintenance** | As per OEM requirements – annual integrity checks and | As per OEM requirements | Outsourced |

| | | | | |
|---|---|---|---|---|
| | **[Communication systems and balance of plant]** | corrective action | | |
| | ***Calibration of active I-V curve optimisation system per string, including maintenance (*where installed)** | At least twice a year for the full plant and after every repair, replacement/adjustment undertaken on a string | As per OEM requirements | Outsourced |
| | ***Maintenance of active expected yield calculation system that takes into account temperature of modules and incident solar insolation (*where installed)** | Twice a year | As per OEM requirements | Outsourced |
| **Contractual Obligations** | **Corrective maintenance** | When required | This must be carried out when it is required and must be done so as to maintain the plant quality, safety and product guarantees and warranties | Outsourced unless otherwise specified in the above line items |
| | **Real-time performance monitoring and reporting** | Real time | Showing the total yield of the plant, the kWhs used by the airport and the kWhs exported to the grid | Outsourced |
| | **Monthly service reports detailing all the maintenance and corrective actions with route cause analysis where relevant** | Monthly | Service reports including the performance of the plant and comparison against the expected performance of the plant with real time performance monitoring results | Outsourced |
| | **Knowledge transfer for two ACSA employees every quarter on all issues with respect to this contract's scope of works** | Shadowing, mentoring, teaching as per knowledge transfer requirements below | This knowledge transfer must cover technical and administrative aspects | Knowledge Transfer for two resources per solar PV plant and must cover the entire maintenance contract on technical issues as well as administrative tasks, competencies required and practical experience which must be acquired during the management of the contract |
| | **Preparation and lodging of claims on equipment warranties/guarantees on behalf of ACSA** | When required | This must be carried out as per the requirements of each OEM | Outsourced |

**Table 5: Knowledge and Skills Transfer Requirements to be Performed Successfully for fully Insourcing Solar PV Maintenance at Airports**

| | | |
|---|---|---|
| **At Least Three Personnel per Solar PV Plant. The following must be Achieved Annually for the full Scope of the Maintenance Contract:** | | |
| **1** | **A Theoretical Class every Quarter, Explaining Concepts of the Solar PV Plant Maintenance to be done in the following Quarter** | |
| | (a) | This theoretical class must have formal notes |
| | (b) | This class must have a verbal, interactive session where team members can ask questions |
| | (c) | This class must be followed up with an evaluation to test the knowledge transfer |
| | (d) | An evaluation report of the team member's performance must be written up, providing insight on the candidate's learning gaps and readiness to perform the works tasks on site |
| | (e) | Any lack in qualifications of the candidate to legally perform the maintenance tasks must be highlighted and submitted within the report |
| | (f) | Registers and the evaluations must be kept as evidence that this task has been completed and must be submitted to the plant owner |
| | (g) | A soft copy of ALL training material must be provided to the plant owner |
| **2** | **Practical onsite work must be undertaken on the solar PV plant every maintenance cycle (quarterly as a minimum and when required for corrective maintenance) ensuring that all maintenance tasks are included in the scope of the practical work** | |
| | (a) | The work tasks (both preventative and corrective maintenance tasks) must be demonstrated by the contractor with the candidate in attention, after which the candidate will safely attempt the task under the guidance of the contractor, until the candidate is confident to do the task on their own |
| | (b) | Once the candidate is confident in doing the task on their own, the contractor writes this up, including evidence of the candidate having been practically trained and undertaking the task confidently on their own (safely and without risk to any warranties or guarantees) and submitted to the plant owner. The write-up must include professional feedback on the candidate's performance including the tools and any competencies that s/he will need to have should s/he undertake the task without the tools and supervision of the contractor. The candidates' signature on the report as being a true reflection of what transpired during the onsite work must be captured. |
| | (c) | Attendance registers and photos must be used as evidence as well as signed off check sheets of who performed each task on the maintenance checklist and report that follows. All of this must be submitted to the plant owner |
| | (d) | The candidate must produce a write-up on the site work performed and comment on his/her confidence to undertake the maintenance un-aided and this must be submitted to the plant owner |
| **3** | **Calibration, programming of parameters where required in this contract, measuring of efficiencies and administrative tasks such as putting in claims, report writing on performance of the solar PV plant must be covered** | |
| | (a) | Each candidate must be able to perform calibration, programming and adjusting of solar PV plant parameters where required, measuring and calculating of plant and component efficiencies effectively and confidently, understanding all concepts and underlying principles involved with each of these tasks which must be covered in the quarterly theoretical class outlined above |
| | (b) | One monthly report every year must be undertaken by the candidate on the form that the contractor reports on a monthly basis. The candidate must do the report independently and the contractor must not do any of the work for this report. The contractor must sign in approval of this report as being true and accurate. Learning to write this report must be done in other months where the contractor usually submits this report. |
| | (c) | At least one claim against the guarantee/warranty for the plant must be completed by the candidate Evidence of this must be presented, such as report write-ups, emails sent, communications and liaisons recorded. This does not need to be done annually but can be done once per candidate for the duration of the contract. |

**Table 6: Outlining the Typical Work Involved, Skills and Certification Required, and Equipment needed for the Insourced Solar PV Maintenance Tasks**

| | Task | In-House/ Outsource | Typical Work Involved | Notes | Skills | Certification | Equipment Required |
|---|---|---|---|---|---|---|---|
| **Solar PV Plant Major Components** | **Array and Grid Junction box Maintenance** | In-house | Visual check for connection and thermographic scan for hot connections | Quick repair mainly involving replacement of connector- no effect on electrical loads | Qualified electrician with IR scanning training | Trade Test, Thermography certificate (3-day course) | Thermal imaging camera, printer, electrical cable connectors for replacement of defective connectors |
| **Solar PV Plant Supporting Systems** | **Earthing Integrity Check, Maintenance and Corrective Action** | In-house | Tightening of earth connections and checking bonding between steel structures and earth mat, annual resistance check using a device commonly known as the "Meggertest" (an earth resistance tester to measure the soil [earth] resistivity) | Requires each airport to have an insulation resistance tester (Meggertest); which most airports have onsite | Qualified electrician | Trade Test | Require an insulation resistance tester known as a "Meggertest" |
| | **LV and MV Cabling Integrity Checks and Corrective Action** | Preventative maintenance to be done in-house. Outsource corrective maintenance | Repairing of damaged or compromised cabling mainly buried underground | Skills for repairing MV cable joints may not be present at each airport; these cables are also buried underground and are labour intensive | Qualified electrician | Trade Test | Visual checks required, so good eyesight and knowledge of how a healthy cable should appear |
| | **Structural integrity Check and Corrective Action** | In-house | Checks for corrosion and loose/failed bolts, loose connections | Major structural failure to be handled differently | Qualified electrician | Trade Test | Visual checks required, so good eyesight and knowledge of a joint/structural beams free of corrosion should appear to and be seen going into the ground, properly secured without compromise |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Vegetation Management** | In-house | Grass cutting with caution of flying debris causing damage to panels | Manage risk of panel damage | Grass cutting/Vegetation management | On the job training - minimum PPE | Requires grass cutting machine(s), fuel and safety gear, taking precaution to first clear the field of stones and objects that can cause damage to panels |

## CONCLUSIONS

This paper presented standards and guidelines for solar PV installations at airports and the proposal for solar PV maintenance to be insourced. The standards and guidelines for solar PV installations addressed the technical aspects of the solar PV plant, including the design aspects, installation aspects, solar PV specifications, operational parameters and output, environmental impact; testing commissioning and handover requirements including insurance underwriting and the SACAA, ICAO and knowledge transfer requirements. The proposed insourced/outsourced solar PV maintenance model is intended to be fully insourced in due course which will save about 30 % on operational cost. A fully insourced solar PV maintenance model ensures that the airports have cost effective maintenance and operations for business sustainability as well as presenting commercial opportunities due to the skills capacity built within the organisation.

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